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Assessment of Advanced Cockpit Displays for General Aviation Aircraft – The Capstone Program

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16. Abstract

Since the inception of the Capstone Program, approximately 150 aircraft in the area of Bethel, Alaska have received a suite of ADS-B displays. Despite the opportunity provided by the large number of ADS-B-capable aircraft in the Bethel area, very little information has been collected from the owner/operators and pilots of these aircraft that might help in transitioning the technology to the rest of the country. To remedy this situation, a team of human factors experts was tasked with travelling to Bethel in March 2002 to collect data regarding the use of these displays in day-to-day flight activities. A total of 41 pilots participated in the interview process, representing nine different flight companies in the Bethel area. All of the pilots were male. The average age was 37, ranging from 21 to 58. The average number of flight hours for the pilots was 4,962 hours, ranging from 950 hours to 30,000 hours. The median number of total flight hours was 3,250. Over 95% (39) of the pilots were instrument rated. Results from the pilot interviews and self-administered questionnaires revealed a number of human factors design, safety, and training issues. Discussion of these results will focus on display design and training recommendations for ADS-B displays that will ease the training burden, mitigate safety hazards, and accentuate safety improvements.

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Assessment of Advanced Cockpit Displays for General Aviation Aircraft – The Capstone Program

INTRODUCTION

Background

In an effort to improve flight safety in Alaska, the Federal Aviation Administration (FAA) has been conducting an assessment of new cockpit avionics for general aviation (GA) aircraft. The assessment is being performed under the FAA's Alaska Capstone Program, which has focused its efforts in and around the town of Bethel, located in the southwest region of the state. The avionics system, developed by UPS Aviation Technologies, consists of a multi-function display unit, the Apollo MX-20, and an accompanying Global Positioning System (GPS) display, an Apollo GX-60. In addition, each aircraft is equipped with a Universal Access Transceiver (UAT), which is a remote-mounted (i.e., outside of the cockpit) radio that provides datalink communication between the aircraft and a ground station or from one aircraft to another aircraft. Participants in the assessment are Part 135 airline operators and pilots in the Bethel area. Approximately 150 GA aircraft have been equipped with the advanced avionics equipment. Figure 1 shows the avionics that are installed in each aircraft participating in the Capstone program.

Display Capabilities

The Capstone displays provide pilots with a moving-map display that shows ownship (i.e., display aircraft) position. Flight plans that are input into the GPS display are presented as a magenta line on the moving map. The map can display an instrument flight chart, with airways, intersections, airports, and other navigational points, or a visual flight rules (VFR) sectional chart that includes terrain features. Many types of information can be overlaid on the map at the pilot's discretion. The display can also show relative terrain in the form of red, green, yellow, or black colored blocks that indicate the relative height of terrain to the aircraft. Using a custom map page, pilots can overlay relative terrain with airport and other information. The display also provides traffic and weather information to the pilot. Certain capabilities available with the Capstone displays, like the display of traffic information, are dependent on a ground/air/space infrastructure known as Automatic Dependent Surveillance – Broadcast, or ADS-B. Some of the capabilities being offered to the GA community under the Capstone program have only been generally available before to commercial airlines and high-end GA aircraft. The ability to see traffic and weather on a cockpit display is usually provided by expensive onboard detection systems. To provide such capabilities in a less expensive manner, a ground-, air-, and satellite-based infrastructure was created — ADS-B. Unlike radar systems that bounce radio waves off of airborne targets and then interpret the reflected signal, ADS-B relies on position information that is transmitted by the UAT from each

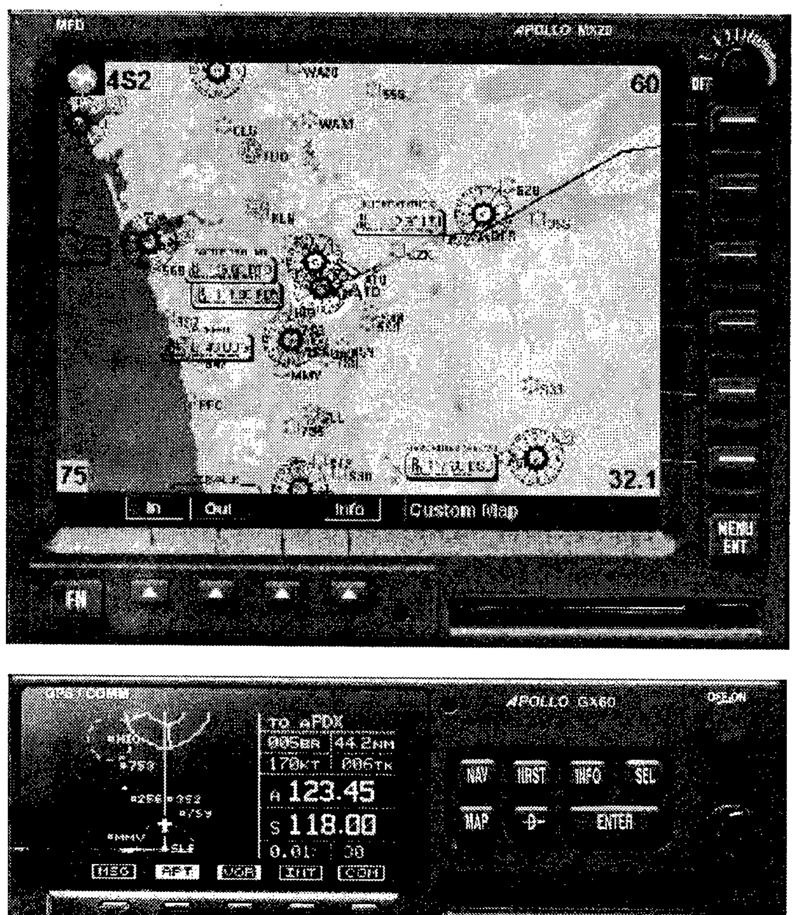


Figure 1: Capstone Avionics displays.

individual aircraft based on GPS technology. Each ADS-B-equipped aircraft broadcasts its precise position in space via a digital datalink, along with other data that includes the aircraft call sign. This information can be transmitted directly from one aircraft to another, or it can be transmitted to a ground station, combined with other aircraft data, and re-transmitted back to any aircraft within range of the ground station. The information can also be transmitted by landlines or other means to air traffic controllers in distant locations. ADS-B allows pilots in the cockpit and air traffic controllers on the ground to "see" aircraft traffic with much more precision than has ever been possible before. Unlike conventional radar, ADS-B works at low altitudes and is effective in remote areas or in mountainous terrain where there is no radar coverage, or where radar coverage is limited.

In addition to information related to other aircraft, other types of information can be broadcast from ground stations to UAT-equipped airplanes. Flight Information Services – Broadcast, or FIS-B, include graphical weather depictions, as well as text-based weather. Future implementations will include other information such as notifications to airmen (NOTAMS). Since weather plays a part in many aircraft accidents, the display of current weather conditions in an easily interpreted graphical format is expected to be of great help to pilots. The graphical depiction of NOTAMS, such as the fact that a runway has been closed at a particular airport, should also make it easier for pilots to maintain awareness of important information both before and during their flights. At present, however, only graphical and textual weather information is transmitted to pilots in the Bethel area.

Safe Flight 21 – Human Factors Team

An opportunity was provided by the large number of ADS-B capable aircraft in the Bethel area to collect information from owner/operators and pilots of these aircraft that might help in transitioning the technology to the rest of the country. To take advantage of this situation, the FAA's Safe Flight 21 Office formed a team of human factors experts to collect subjective data from the airline operators and pilots in the Bethel area. Safe Flight 21 and the Capstone Office are partners in the development of data link technologies. The human factors team, aided by personnel from the University of Alaska at Anchorage (UAA), traveled to Bethel to collect data regarding the use of these displays in day-to-day flight activities. While it is assumed that some flight activities are unique to the Alaska area, and some design issues are unique to the MX-20 and GX-60, it was also believed that information could be collected that would relate to safety, training, and human factors design that could generalize to other multi-function ADS-B displays. This report is a summary of the Bethel data collection effort.

METHOD

Instruments

A set of data collection instruments was created. This set included a self-administered questionnaire that focused primarily on training and normal usage issues, an interview form for gathering data about the strengths and weaknesses of the display, and a form for collecting demographic data from each of the participants. The Demographic Data Form is shown in Appendix A. The Interview Form is presented in Appendix B, and the Self-Administered Questionnaire is shown in Appendix C. In addition, team members flew on 5 scheduled flights to observe the actual operation of the equipment.

Participants

A total of 41 pilots participated in the interview process. Twenty-seven of the 41 also filled out the self-administered questionnaire form. The 41 pilots that participated represented 9 flight companies in the Bethel area. Only 2 companies with Capstone-equipped aircraft were not represented in the interview or questionnaire process. Both of these companies were single-pilot operations.

All of the pilots were male. Their average age was 37, ranging from 21 to 58. The mean number of flight hours for the pilots was 4,962 hours, ranging from 950 hours to 30,000 hours. The median number of flight hours was 3,250. Over 95% (39) of the pilots were instrument rated. Approximately 63% (26) of the pilots had used a handheld GPS unit, typically one of the Garmin models. Mean use of Capstone equipment was 884 hours, ranging from 6 to 3,000 hours.

Procedure

A team of four members of the Safe Flight 21 Human Factors Group visited Bethel from March 9th to the 17th, 2002. They were accompanied to Bethel by Professor Leonard Kirk, from the UAA, who had conducted much of the training for the Capstone equipment and was familiar with most of the pilots and company owners in the area. Initial contact with many of the flight companies was through Mr. Kirk.

Except for one focus group of 5 pilots, all interviews were conducted in a one-on-one manner. During initial contact with each of the flight companies,

the self-administered questionnaires were given to whomever was in charge to distribute to each of the company pilots. Each day, all flight companies were visited to conduct interviews with available pilots and to pick up any completed questionnaires. Approximately 60 self-administered questionnaires were delivered. The 27 questionnaires returned yields a response rate of 45%.

RESULTS AND DISCUSSION

Negative Safety Implications

Degradation of Conventional Flying Skills

Pilots were asked to rate how they felt their conventional navigational skills had been affected as a result of using the Capstone avionics. Results are presented in Figure 2. The majority of pilots (23) felt that their conventional navigational skills had not been affected.

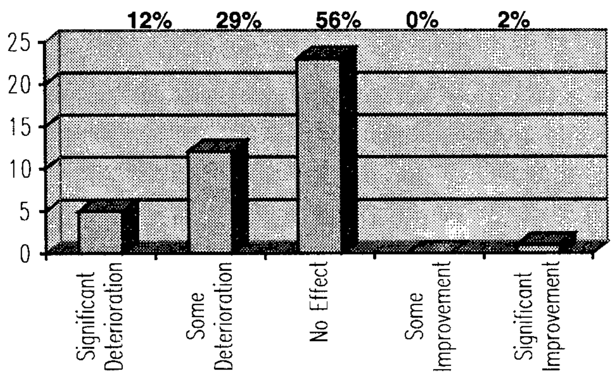


Figure 2: Rate the amount you feel your conventional navigational skills have been affected as a result of using Capstone avionics?

However, a large proportion of pilots (17, or 41%) believed there had been some degree of deterioration in their navigational skills. The chief concern among these pilots was whether they could fly and navigate using conventional methods (i.e. radio navigation aids, pilotage, dead-reckoning) if their Capstone equipment failed or malfunctioned. As more of this equipment makes its way into GA cockpits, more pilots could become dependent on these displays and lose conventional navigational skills.

Even if conventional navigational skills do not deteriorate, there is still a danger of being unable to navigate after the loss of a moving-map display. This is because most conventional methods of navigation rely on the periodic update of information in a specific manner. Pilots must prepare before a flight to navigate using, for example, VORs and NDBs. They must know which frequencies to use during the flight to make use of this equipment, and they must know during the flight the relative position of VOR and NDB stations. The same can be said regarding dead-reckoning skills. If pilots have not kept track of how long a specific heading has been held, they will be unable to use dead-reckoning skills mid-flight to judge location.

Mixed Equipage

Thirteen pilots (32%) commented during interviews that mixed equipage was a problem, focusing around the idea that pilots start to rely too heavily on the traffic display and forget to look outside for aircraft. Similar problems with failing to look outside the cockpit have been documented among Part 121 pilots using the Traffic Collision Avoidance System (TCAS) (Foy & McGuinness, 2000). Several pilots reported near mid-air collisions with non-Capstone equipped aircraft. One example in particular involved a near-miss with a B-727. The pilot stated that he was 8-9 miles from Dillingham when he observed a B-727 pass within 60-80 feet to the left side of his aircraft at his altitude. The pilot stated that what probably saved him was that he was slightly off course to one side of the localizer. The pilot commented that "in order for this equipment to really enhance safety, all aircraft must be participating."

Terrain Database Inaccuracies

An incomplete terrain database can lead to a dangerous situation. One of the pilots noted during an interview that some "mud volcanoes" did not appear in the terrain database or on the map page. Since these terrain features rise up to over 600 feet, they pose a danger to pilots that might not be aware of their exact position, especially in low visibility conditions. However, it should be noted that the inaccuracy of the database could not be verified.

Incorrect Barometric Pressure Reports

The relative terrain mode can be inaccurate if the current altimeter setting is input incorrectly or not at all, or if pressure changes drastically during the flight, thereby rendering the altimeter setting incorrect. A second problem, mentioned by one of the pilots during an interview, is that the barometric pressures noted at certain locations are often inaccurate because of the sparse availability of reporting stations in the area. Another problem area involving barometric pressure is that pilots are required to input barometric pressure in both the GPS and MFD separately, as well as the altimeter display, which increases pilot workload and the chance for human error.

Increased Head-Down Time

The introduction of new systems into GA cockpits has the potential to increase pilot workload and reduce pilot situation awareness, particularly immediately after installation (Williams, 2002). Many of the pilots reported that they had very little training or understanding of the system before actually flying alone with it. Responses from the self-administered questionnaire indicated that only 50% of the pilots, averaged across the functions, received formal training on specific functions on the MX-20. For the GX-60, 40% of the pilots, on average, received formal training on specific functions. Individual pilot training was the responsibility of each flight company, and many companies did not have a formal training curriculum for pilots using the systems. Pilots stated that during these early flights they spent a considerable amount of head-down time attempting to select and exercise system functions.

Increased Risk-Taking

Participants were asked whether the use of the displays would increase pilot risk-taking behavior. Results are shown in Figure 3.

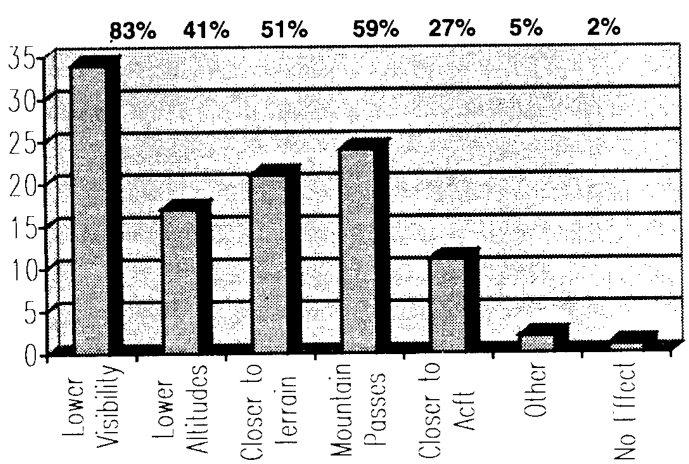


Figure 3. Has the Capstone equipment increased, or will it increase any of the following types of risk-taking behaviors: 1) Flying under **lower visibility** conditions; 2) Flying at **lower altitudes** under low visibility conditions; 3) Flying **closer to** hazardous **terrain** features (mountains, hills) under low visibility conditions; 4) Flying through **mountain passes** when weather is questionable or visibility is low; 5) Flying **closer to** other **aircraft**, even if it is difficult to maintain constant visual awareness of their position; 6) **Other** types of risk-taking behavior; or 7) The equipment will have **no effect** on risk-taking behavior?

Eighty-three percent (34) of the interviewed pilots believed that there would be or already is an increased tendency to fly under lower visibility conditions using the displays than if they were unavailable. Between 40% and 60% of the interviewed pilots also believed that there would be an increased tendency to fly at lower altitudes under low visibility conditions, to fly closer to hazardous terrain features, such as mountains and hills, under low visibility conditions, and to fly through mountain passes when weather is questionable or visibility is low. Two "Other" types of risk-taking behaviors mentioned were flying in all types of hazardous weather conditions and flying to a new destination without using any paper maps or charts.

Positive Safety Implications

Increased Navigational Awareness

Despite the above-stated negative safety implications of how these displays were used, many positive points were brought out in the interviews and questionnaires. One statement made by the pilots was that the moving map display increased their awareness of terrain and airports during flight. The moving map display is thought to be especially useful for maintaining awareness of the location of a runway under low-visibility conditions. The map display was also helpful for locating runways that had never been visited or had been visited rarely. Another way in which the moving map display assisted in navigation was in helping the pilot to distinguish between mountain passes that look very similar out-the-window.

Pilots filling out the self-administered questionnaire reported that relative terrain information was used approximately 10% of the time, on average. Individual usage varied from 0% to 100%. The finding that pilots did not use the terrain information very often makes sense, given that most of the flying done in the area is under visual flight rules. Pilots stated that, when they were somewhat unfamiliar with an area or unsure of the location of the correct pass, they would call up the Terrain mode (or use the Custom mode with relative altitude displayed) to isolate the correct pass. This was particularly helpful when visibility was limited and it was more difficult to see distinguishing terrain features. Once inside a pass, it was reportedly not unusual to experience decreasing visibility to the point that all visual references with the surrounding terrain would be lost. The extreme case of loss of visual contact with the ground would occur when the snow-covered ground and clouds would cause a "whiteout" condition where everything outside of the aircraft

looked white. One pilot reported that the Capstone equipment essentially saved his roommate's life when he inadvertently entered a whiteout condition while flying through a pass. His roommate told him that he selected the terrain page and flew through the pass, staying within the yellow color-coded area on the display.

When asked about the effect that the equipment had on conventional navigational skills, one pilot stated that his skills had significantly improved as a result of using the Capstone equipment. His reasoning was that the GPS display gives you an instant picture of the required wind correction angle to hold a course (i.e. Wind correction angle = current heading - current track when current track = desired track). The only way to accomplish that with ground based navigational displays is by "bracketing" a course until you eliminate the drift. This "precise" experience with GPS navigation helps the pilot make better estimates of drift correction when relying solely on ground aids. Also, at distances over 30 miles from the station, a course line to or from a VOR becomes wider than a GPS course line to the same location. Because CDI sensitivity is generally set to 5 miles for en route GPS navigation, a pilot could see a GPS CDI that is slightly off-center when the VOR CDI is fully centered. The converse of this is true near the VOR because the VOR course is narrower than the same GPS course. These differences could be significant when precise navigation is required to avoid obstacles. Pilots with GPS experience might make better decisions because they are more likely to be aware of the limitations of both forms of navigation.

Increased Ability to Avoid Traffic

Unlike the display of relative terrain, pilots would always display traffic on their MX-20, either with the dedicated traffic page or as an overlay on another page. Pilots were asked what effect they believe the traffic display will have on the rate of near mid-air collisions. Results are presented below in Figure 4.

The majority of pilots interviewed believe that the display of traffic reduces the possibility of mid-air accidents. Pilots believe they become aware of traffic more quickly using the MX-20 traffic display. Pilots also believe they are able to alter their flight path earlier to avoid close contact with other aircraft in the area.

Maintaining Aircraft Separation during Holding Procedures

Nineteen pilots (46%) commented during their interview that the traffic display was most useful during holding procedures for maintaining aircraft spacing. During marginal VFR weather conditions, aircraft reportedly are sometimes required to remain in a holding pattern for long periods of time (reportedly up to an hour and a half) while IFR aircraft under the control of Anchorage Center are landing. The marginal weather conditions make it difficult to maintain visual contact with other aircraft in the holding pattern.

Ability to be Visible If Communications are Lost

Two pilots mentioned during their interview that if radio communications failed in the aircraft, they would be comforted because most of the other pilots in the vicinity could still see them on their traffic display.

Recognizing Waypoint Entry Errors

After pilots input a waypoint into a flight plan or use the direct-to function, the route from the current aircraft position to the waypoint is indicated on the moving map display. This route line provides a validation to the pilot that the waypoint information was input correctly. Two pilots noted that they became aware of incorrectly entering a waypoint after noticing the route line depiction on the moving map display.

Training Implications

Familiarity with Display Features

Two pilots remarked during the interviews that it was disconcerting that traffic could not be overlaid on the terrain page. These pilots were not aware that traffic could be overlaid on the terrain page using the custom map, but that it had to be accomplished through a different menu and that it took several keystrokes. During times when much traffic was presented on the screen, pilots would select different range values to declutter the display. Two pilots remarked that there were times when too many aircraft

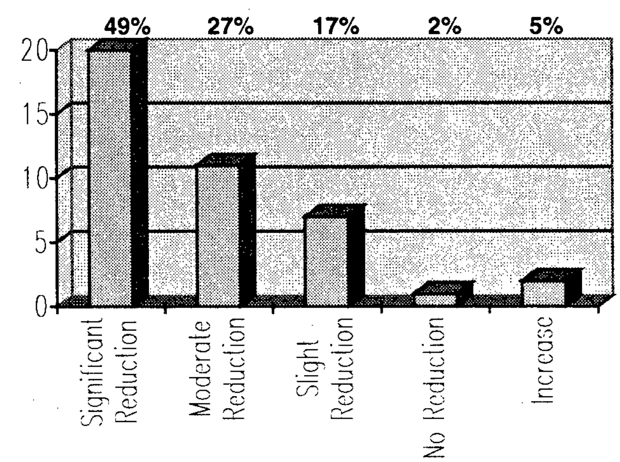


Figure 4: What effect (if any) will the Capstone equipment have on the rate of near mid air collisions?

were presented on the display. These pilots were not aware of the altitude band function (± 2000 feet from the own aircraft altitude) that was available. Other pilots, who were aware of the altitude band, wanted the capability to select a narrower band, such as ± 1500 feet or ± 1000 feet, to further declutter the display.

Transmitted Altitude

Three pilots revealed that they knew of pilots who were not inputting the correct barometric pressure, but rather inputting a pressure that would indicate they were higher than they were actually flying. These pilots assumed that in doing this, they were protecting themselves from possible punitive action by the FAA for flying below legal altitude limits. These pilots were not aware that the encoded altitude transmitted via the data link is based on standard pressure altitude (i.e., 29.92 inches) and, therefore, not affected by the barometric pressure setting.

Training Consistency

The receipt of adequate training and familiarity with this type of equipment continues to be a problem. Pilots operating out of Bethel have had a range of training on this equipment. During one-on-one interviews, some pilots reported they were only shown how to turn it on and bring up the Map page for the MX-20, and perform a Direct-To with the GPS (the GX-60). Other pilots stated they received extensive training on both the GX-60 and MX-20 from instructors at the University of Alaska, Anchorage (UAA). This training was conducted over a 2-day period and included training on inserting and editing a flight plan, selection of display options, and other functions associated with the system. These pilots seemed the most knowledgeable of the system. However, even for these pilots, the complexity of the system and reliance on memory to access information and select various functions, caused many of them to focus on and use a small subset of system functions.

Pilots filling out the self-administered questionnaire indicated, for each of several functions on both the MX-20 and GX-60, what type of training they received for that function. Pilots indicated whether they learned the function through formal training provided by their flight company or the UAA; through self-study with the system manual and equipment; by means of a Capstone or other computer simulation; by being shown the procedure by another pilot; or that they had received no training for the function. Figure 5 indicates the results of the pilot responses, averaged across functions, for both the MX-20 and the GX-60.

Figure 5 shows that 51% of the pilots, on average, claimed they received formal training on the set of MX-20 functions listed in the questionnaire. On the other hand, only 40% of the pilots said they received formal training on GX-60 functions. This list of functions can be found in Appendix C and also in the next section entitled "Use of Minimum Functionality."

Use of Minimum Functionality

Pilots that filled out the self-administered questionnaire were asked to indicate how often they made use of particular functions on both the MX-20 and GX-60. Pilots indicated, for each of several functions, whether the function was used all the time, sometimes, rarely, or never. Results are shown below in Figures 6a-q, listed under "MX-20 Functions" and 7a-t, listed under "GX-60 Functions."

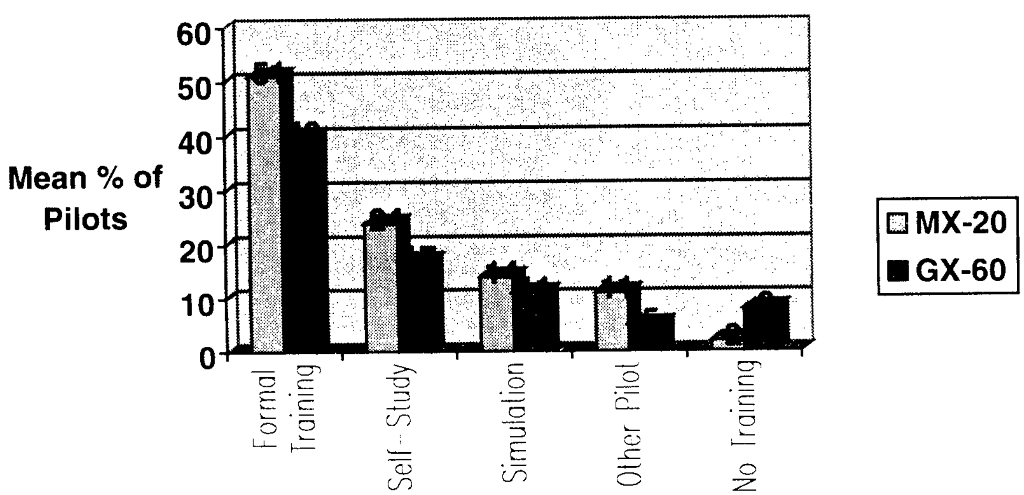
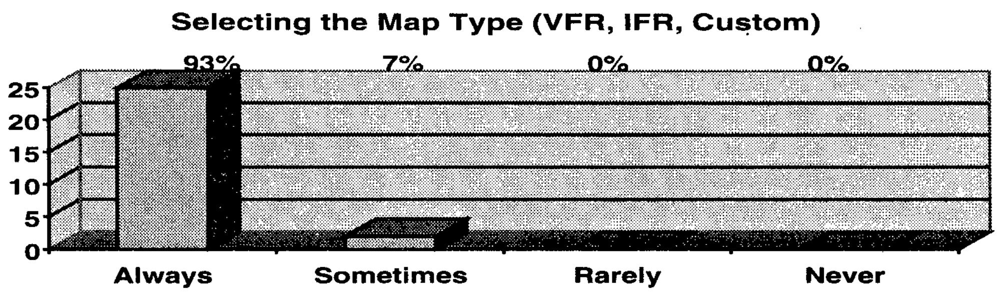


Figure 5: Training type estimates across functions for MX-20 and GX-50 units.

MX-20 Functions

a. Selecting the Map Type

The MX20 displays 3 types of moving map—IFR, VFR and Custom. The IFR selection depicts an IFR chart. The VFR map displays color-coded terrain and surface features (roads, lakes, etc) similar to a sectional chart. The CUSTOM map is a pilot-customizable version of the VFR map. It provides several menu pages of selections to display airways, navaids, airports, surface features, and relative terrain information.



a

b. Selecting the Map Orientation

The MX20 will display the moving map in the following orientations:

Track Up – the actual ground track of the aircraft is toward the top of the display.

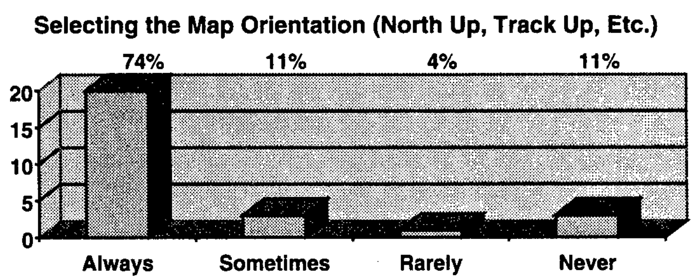
Track up Arc– same as Track Up with a semicircle compass rose and the aircraft's track displayed at the top of the screen.

Track up 360 – same as Track Up with the ownship symbol in the center of a compass rose, in the center of the display.

Desired Track Up– the course to be followed is oriented toward the top of the screen.

North Up – Magnetic North is always at the top of the display.

The pilot can select any of these in each map page.



b

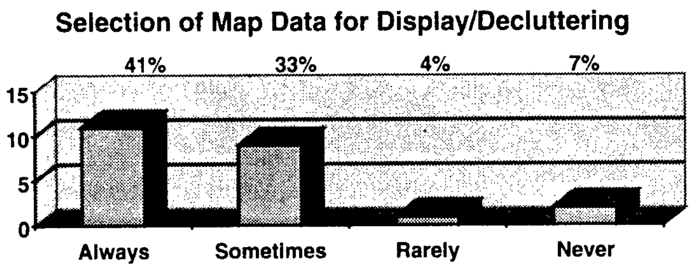
Pilots answering the self-administered questionnaire were asked to indicate the percentage of time that they spent in each of the various map orientations. Results indicated that 1 pilot used the North up orientation exclusively. One pilot switched between North Up and Track Up. The rest of the pilots (25 of 27, or 93%) used one or more of the Track Up orientations. None of the pilots used the Desired Track Up (DTK) orientation. Averaging the percentages across pilots, we find the following usage estimates:

- Track Up: 15%
- Track Up Arc: 38%
- Track Up 360: 43%
- Desired Track Up: 0%
- North Up: 7%

It should be noted that the validity of these percentages is suspect for a variety of reasons. Pilots did not ensure that individual percentage estimates across orientations added up to 100%. One pilot, for example, estimated that he spent 90% of the time in the North Up orientation and 90% of the time in the Track Up orientation. It is also unclear whether pilots understood the different types of track up orientations. What is fairly certain is that most pilots used one of the track up orientations, a couple of pilots used the North Up orientation, and no pilots used the Desired Track Up orientation.

c. Selection of Map Data for Display/ Decluttering

Each map type has various levels of information to display. (navaids, airways, intersections, etc.) The pilot can selectively display the symbols and labels with the menu keys on the right-hand side of the display.

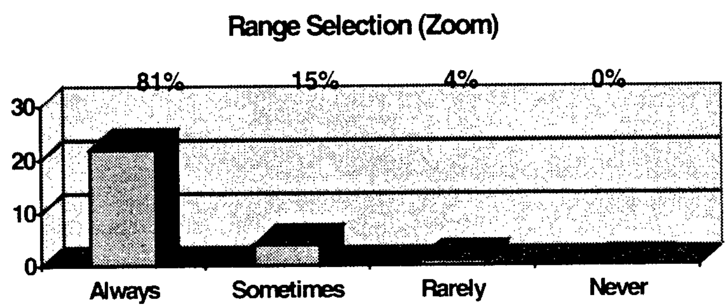


c

d. Range Selection (Zoom)

The pilot can scale the map presentation with the (+,-) Zoom keys on the bottom of the display. The range scale could be varied between ¼ mile and 200 miles. There is also an AUTO setting that will keep the ownship and the active waypoint on the screen by increasing the range scale if necessary.

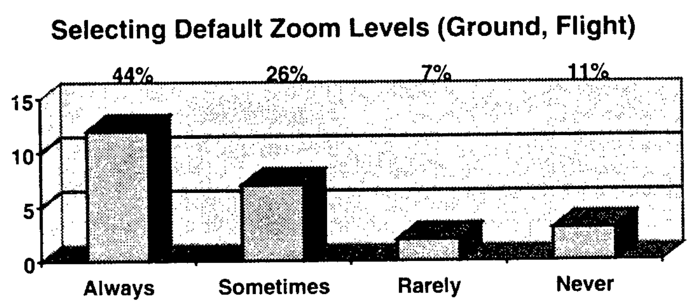
Range selection varied from 2 to 5 miles for ground operations, 5 to 20 miles while in the terminal area and from 5 to 75 miles while en route. Six of the pilots (22%) indicated that they used the AUTO setting while en route.



d

e. Selecting the Range Defaults for Ground and Flight

The pilot can select the default zoom level for ground operations and flight operations, and the aircraft ground speed at which the zoom level will change from ground to flight and vice versa.

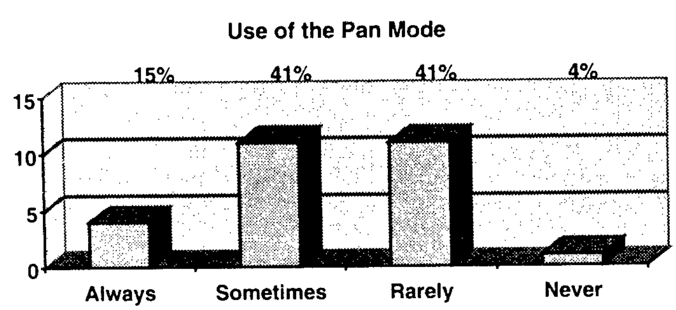


e

f. Use of the Pan Mode

The Pan Mode allows the pilot to move the map up, down, left or right. This is useful to give a full route presentation at a usable/readable zoom level, or simply to see what is ahead.

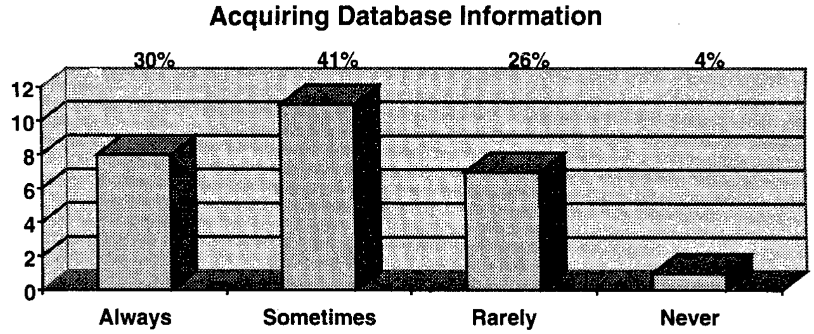
Twelve pilots elaborated on why they rarely or never used the pan mode. Eleven of the 12 stated that they did not need the feature during normal operating procedures. The 12th pilot stated that he only used the feature when travelling to an unfamiliar area to get an idea of what to expect.



f

g. Acquiring Database Information

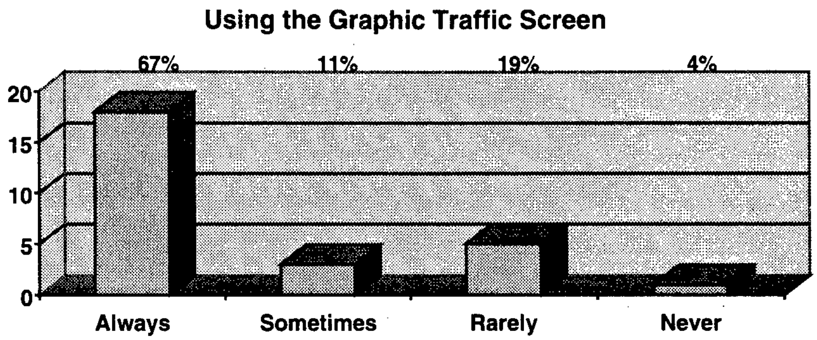
The MX20 has an extensive database of airport/fix/navaid information that is accessible to the pilot from the Flight Plan page or the INFO button on the map pages. In the PAN mode, the INFO button displays information about the airport nearest the aircraft's current location. In the normal mode, the INFO button displays information about the active waypoint.



g

h. Graphic Traffic Screen

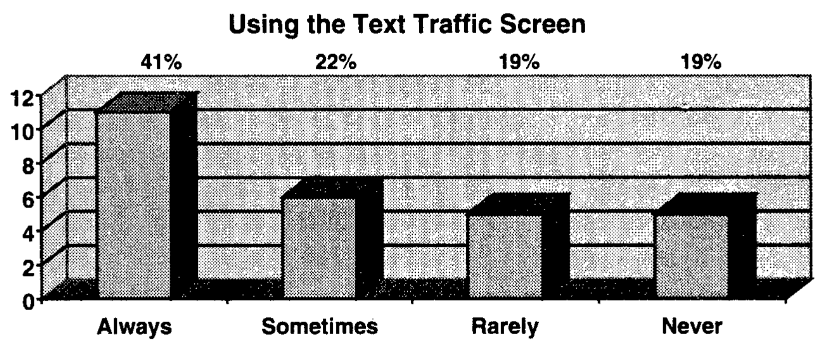
The MX20 has a dedicated ADS-B traffic page that shows the ownship symbol in the center of a compass rose (Track up 360 or arc presentation), the flight plan, and ADS-B targets (traffic). Each target is tagged with its call sign, altitude, a velocity vector and a climb or descent arrow if appropriate. Traffic may also be filtered to depict only those targets within 2000 feet of ownship.



h

i. Using the Text Traffic Screen

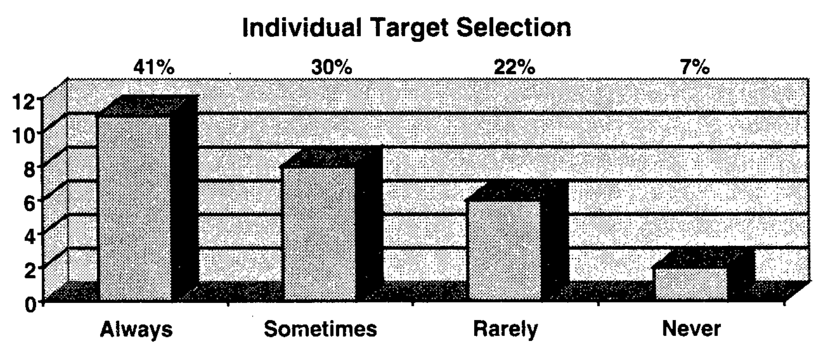
The text traffic screen lists all received ADS-B targets, their call signs, altitudes, ground speeds, and a clock position/distance from ownship.



i

j. Individual Target Selection

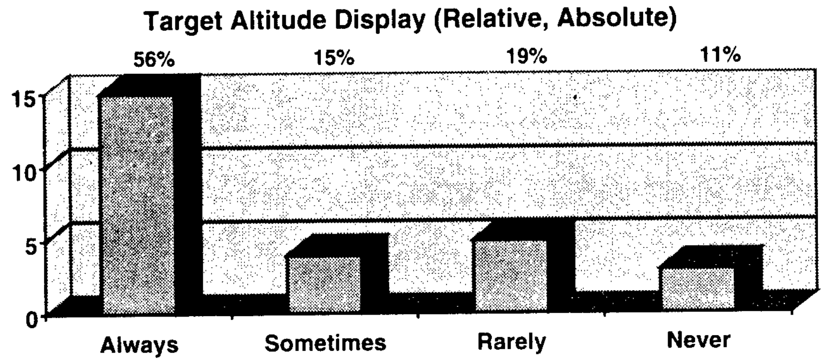
Each target can be individually selected by the pilot to display additional information. This information includes the ground speed of the target, its estimated relative position (e.g., 2 o'clock) and distance.



j

k. Target Altitude Display (Relative, Absolute)

The altitudes displayed can be either the absolute altitude of the target, or relative altitude of the target to ownship.

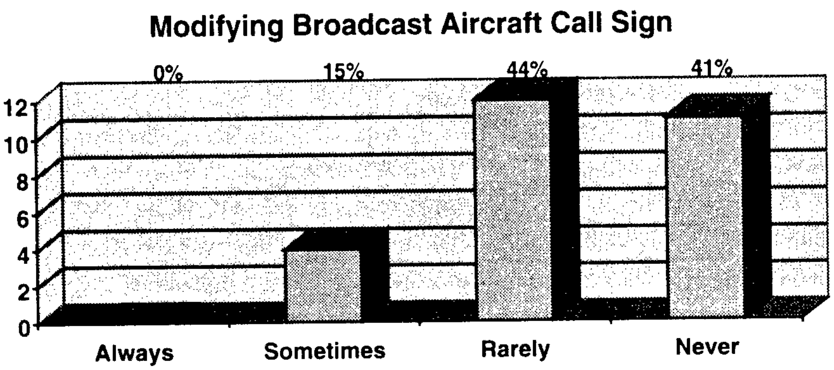


k

l. Modifying Broadcast Aircraft Call Sign

The MX20 allows the pilot to choose the call sign that is broadcast by the UAT. This feature was added to accommodate the potential need for more flexibility or to accommodate a company call sign.

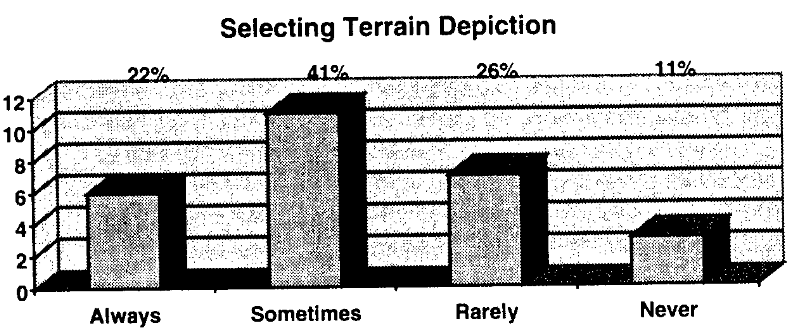
Most of the pilots who rarely or never used this function indicated that the reason it was not used was that it was unnecessary. One pilot wrote that he had been instructed by the Capstone office not to use the function.



l

m. Selecting Terrain Depiction

Terrain is depicted on the VFR map as it is on a sectional chart, with color-coding. Lower terrain is green and higher terrain is in increasingly darker shades that range from yellow to orange. The CUSTOM map allows the pilot to choose between this "absolute" mode and a "relative" mode. In the relative terrain mode, the terrain changes color relative to the aircraft's indicated altitude. In Alaska, the following color-coding is used:

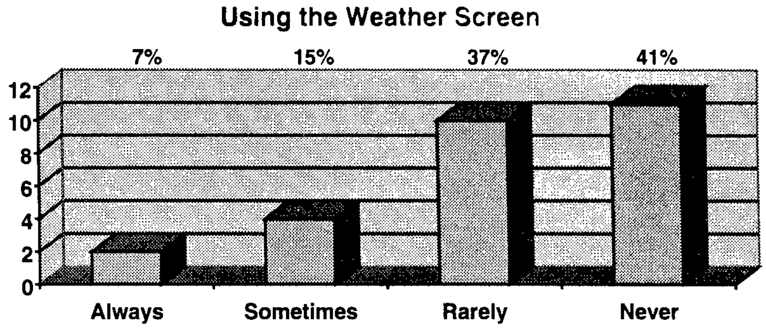


m

- Red means terrain is 300 ft. below, to above the aircraft's altitude
- Yellow indicates terrain is from 301 – 1000 ft. below the aircraft
- Green indicates terrain is from 1001 – 2000 ft. below the aircraft
- Black indicates terrain that is more than 2000 ft. below the aircraft.

There is also a dedicated terrain page that provides only relative terrain and flight plan information. It is imperative that the aircraft and MX-20 have a correct altimeter setting for the relative terrain information to be accurate.

n. Using the Weather Screen

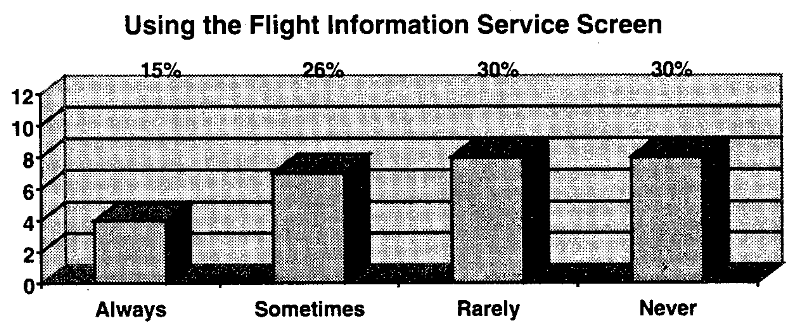


n

The MX-20 can display broadcast graphical weather data (e.g., NEXRAD) on dedicated screens. The weather screen shows the ownship symbol, flight plan and the received weather returns.

When explaining why the function was not used, the most common answer (12 pilots) was that the information was not available most of the time. During pilot interviews, pilots suggested that the weather data were available only about 25% of the time or less. One pilot mentioned that the information only covered a small area around Bethel. Three pilots claimed the information was unnecessary.

o. Using the Flight Information Service Screen

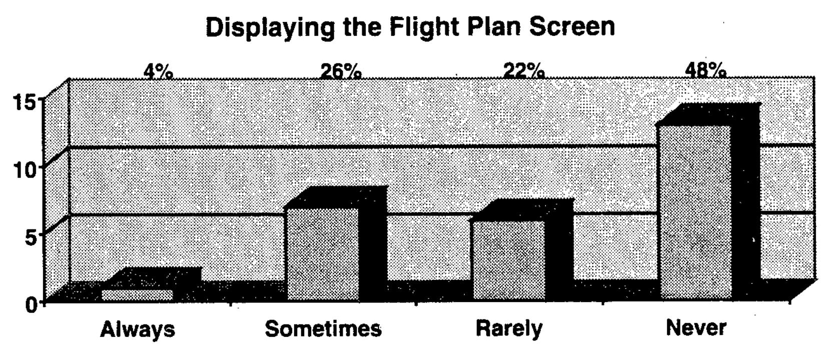


o

The MX-20 can display broadcast textual weather data (e.g., METARS, TAFS) on dedicated screens. The Flight Information screen allows the pilot to select and view all received TAF and METAR reports.

Similar responses were given for not using the textual weather information as were given for the graphical weather information. Six pilots stated that the data was unavailable most of the time; 5 pilots said that the information was not needed; 2 pilots stated that the information was too limited in scope to be useful; and 3 pilots were unaware of the feature.

p. Displaying the Flight Plan Screen



p

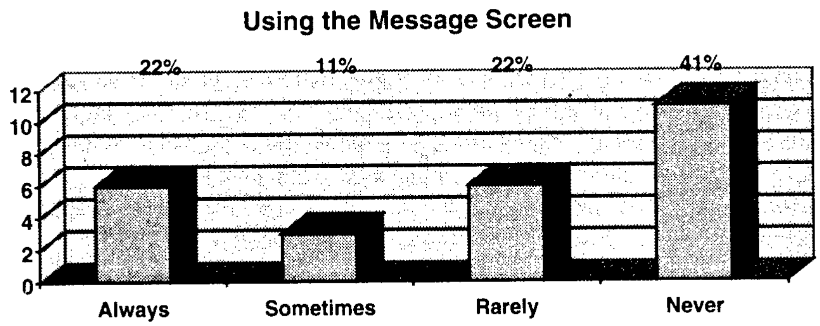
The flight plan screen lists all the waypoints in the current flight plan, the active waypoint, and current navigation information. The pilot can scroll through the waypoints and view database information about each waypoint.

Thirteen pilots stated that this function was not needed. As was mentioned earlier, many pilots did not use the flight planning function of the GX-60 (see Figure 7a below). Three claimed the function was too complex.

q. Using the Message Screen

The message screen allows the pilot to view and clear system messages such as imminent entry into restricted airspace or entry into a terminal area.

Eight pilots stated this function was not necessary. Three said that the message light on the unit blinked continually and they had learned to ignore it. Two claimed that the messages were neither important nor interesting.



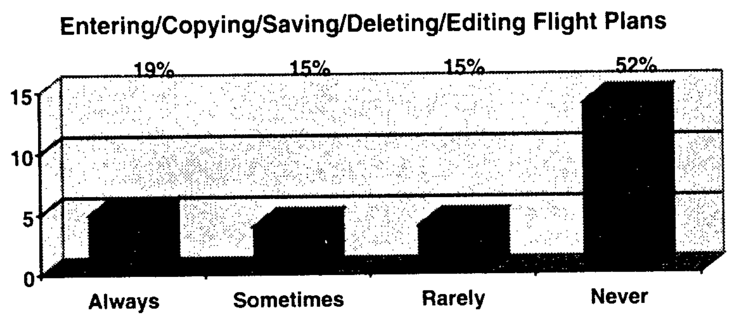
q

Figures 6 a-q show MX-20 function usage estimates.

GX-60 Functions

a. Entering/Copying/Saving/Editing/Deleting Flight Plans

The GX60 allows the pilot to store up to 30 named flight plans. The pilot has full control over the waypoints in each flight plan and can copy them from one location to another, rename, reverse, and delete them. Each flight plan is stored under a user-given name. When activated, the stored flight plan becomes the "Active" flight plan, which is uploaded to the MX20 for display.

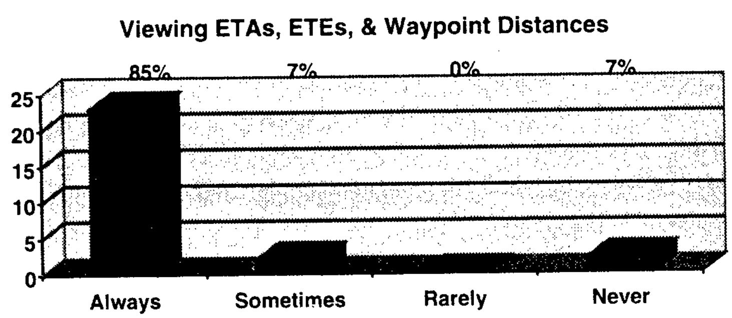


a

Ten pilots stated that the feature was unnecessary. Two said they had not received any training. One pilot claimed the function was too complex. One stated that, when flying to multiple airports, the flight plan would move too quickly to the next leg, before the previous leg had been completed. This made the flight plan function unusable.

b. Viewing ETA's, ETE's and waypoint distances

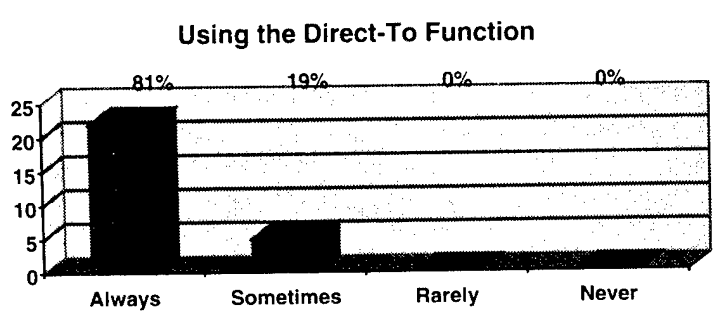
The pilot can scroll through the NAV pages on the GX60 to view estimated time of arrival (ETA), estimated time en route (ETE) and distances to all waypoints in the active flight plan.



b

c. Using the Direct-To function

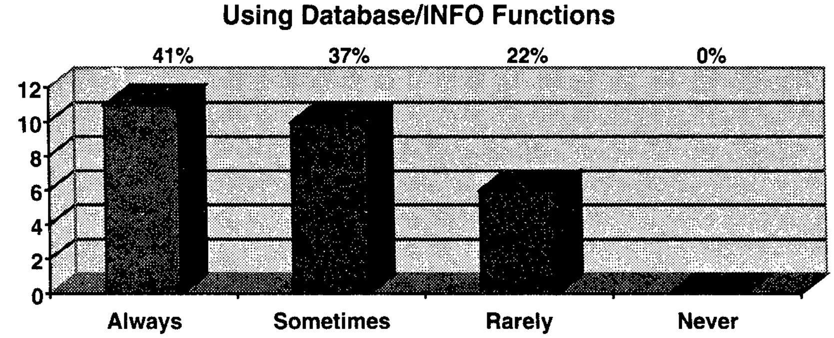
Like all GPS navigators, the GX60's simplest function is to navigate direct to a waypoint. The pilot pushes the Direct-To button, selects the waypoint, and presses Enter. The GX60 will then provide guidance along a course from the aircraft's present position to the selected waypoint.



c

d. Using Database INFO Functions

The GX60 has an extensive database of airport and navaid information. The pilot can access this directly from the database by selecting the DB (database) button along the bottom of the navigator. Access can also be gained by pressing the INFO button when the desired waypoint is displayed on the active waypoint or flight plan page.

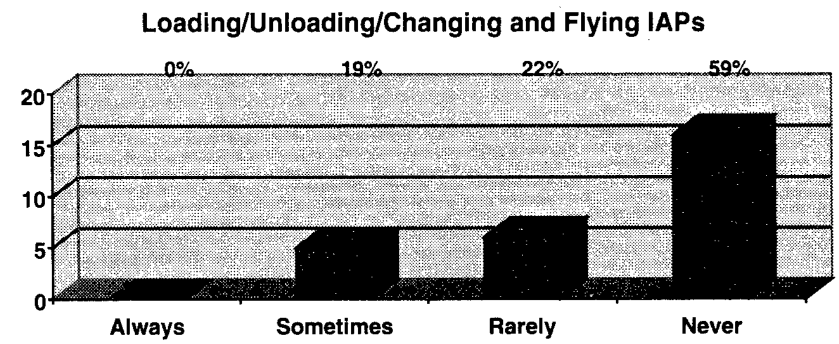


d

e. Loading/ Unloading/Changing Flying IAPs

The GX60 is a C129 GPS navigator approved for approach navigation. When an airport with an approved GPS approach is the destination waypoint in a flight plan, pressing SELECT will load an instrument approach procedure (IAP). When loaded, the fixes for that approach are added to the flight plan. Once an approach is loaded, the pilot has the option to unload, change, or disable the approach procedure.

Instrument approaches are rarely flown in the Bethel area. Twelve of the pilots stated that the function was not needed. Four pilots were unaware of the function. Two pilots said that the company did not allow use of the function.

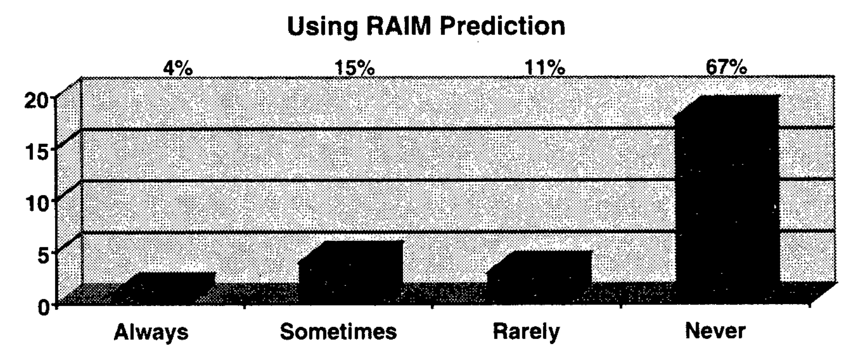


e

f. Using RAIM Prediction

All C129 GPS navigators are required to provide integrity monitoring of the GPS signal to ensure an accurate signal for approach navigation. The Receiver Autonomous Integrity Monitoring (RAIM) function is accessed on a NAV page of the GX60. The pilot can enter an ETA at the destination airport and the RAIM function will predict whether or not GPS signal integrity will be available at that time. This allows the pilot to know in advance whether GPS approaches at that airport will be available.

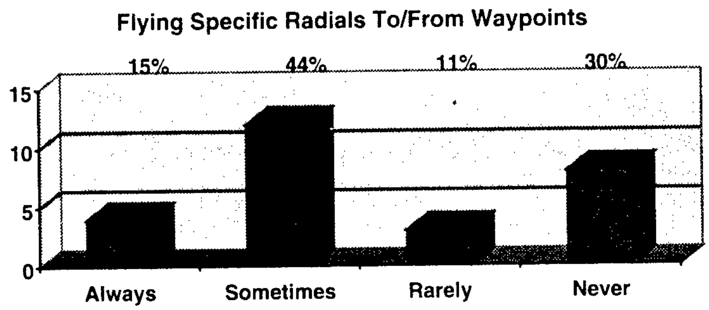
Because instrument procedures are rarely used, there is little need for this function.



f

g. Flying Specific Radials To/From Waypoints

As GPS navigation makes use of standard VOR and other navigation waypoints, it is necessary for the pilot to be able to intercept and fly specific courses to and from waypoints. This is accomplished on the GX60 by making the desired waypoint the active waypoint, pressing Direct-To twice and entering the course to be flown.

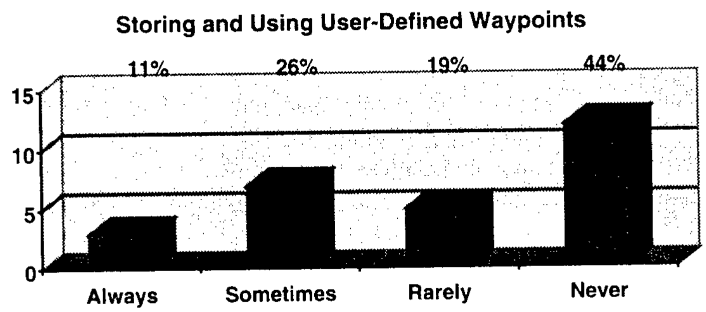


g

h. Storing and Using User-Defined Waypoints

The GX60 offers the pilot the capability to store and navigate using user-defined waypoints. This can be useful for a variety of reasons such as search and rescue and plotting courses around terrain features.

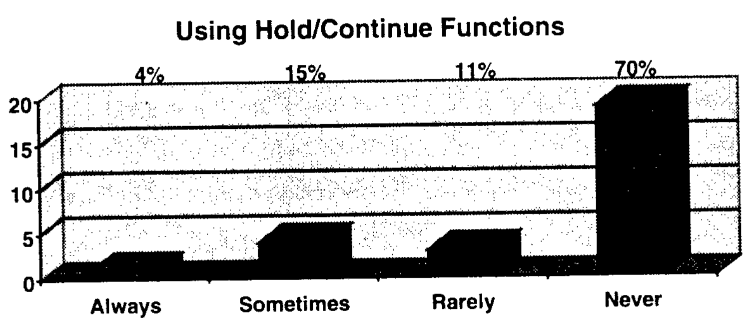
Most of the pilots that rarely or never use the function (11) stated that the function was not needed.



h

i. Using Hold/Continue Functions

Normally the GX60 will automatically sequence through the waypoints in a flight plan as the flight progresses. However, the pilot can control this sequencing with the Hold/Continue functions. This is normally accomplished in an IFR conFigured aircraft with the annunciator panel, but the pilot can elect to leave the current waypoint as the active waypoint after the aircraft has passed it by selecting the Hold function on the GPS. When the pilot selects "Continue," normal sequencing will resume.

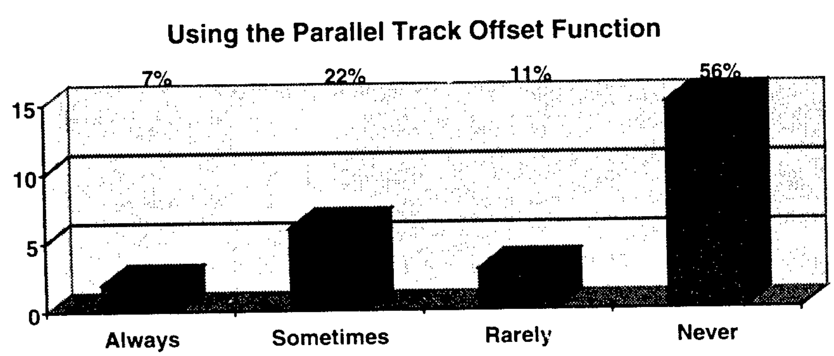


i

j. Using the Parallel Track Offset Function

This function allows the pilot to offset the desired track by a user specified number of miles. This may be useful to avoid head-on traffic situations on busy routes.

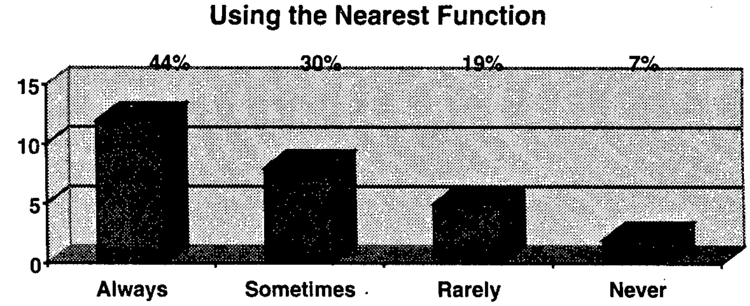
Nine pilots said the function was not necessary; 2 said they had received no or not enough training on the function; 4 pilots were unaware of the function.



j

k. Using the Nearest Function

The nearest function displays the distance and bearing to the 20 nearest waypoints (airports, navaids, intersections, airspaces, etc) to the aircraft's present position. Using this function, along with the INFO function, allows the pilot to select a suitable site for an unanticipated landing, or simply as a way to quickly enter a course to a nearby waypoint.

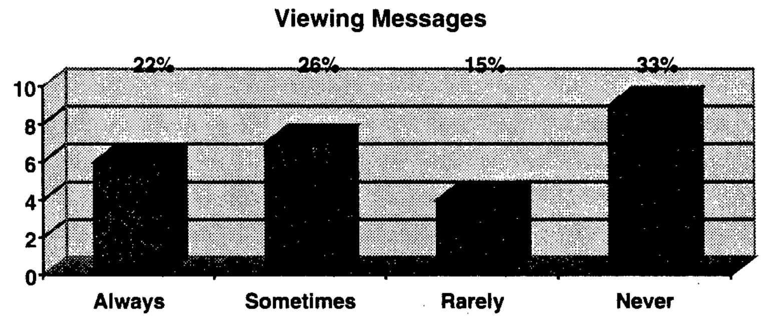


k

l. Viewing Messages

System messages will warn the pilot of entry into protected airspace, loss of satellite signal, and transitions from one waypoint to another during navigation. Pilots can view these messages by pressing the MSG button on the display unit.

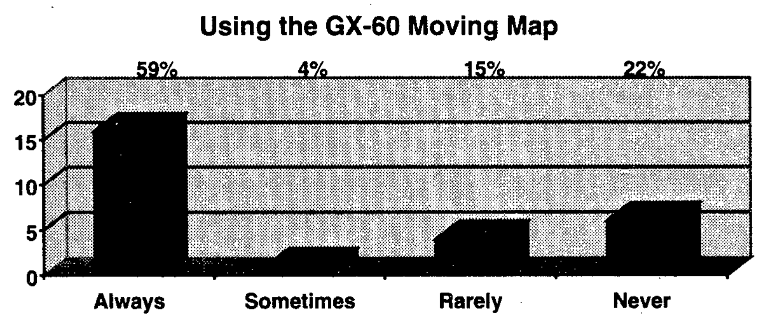
Responses by pilots that never or rarely used the function were similar to those given for viewing MX-20 messages. Three pilots stated the function was unnecessary. One pilot said no or not enough training was received. Two of the pilots said that the messages were always the same.



l

m. Using the GX-60 Moving Map

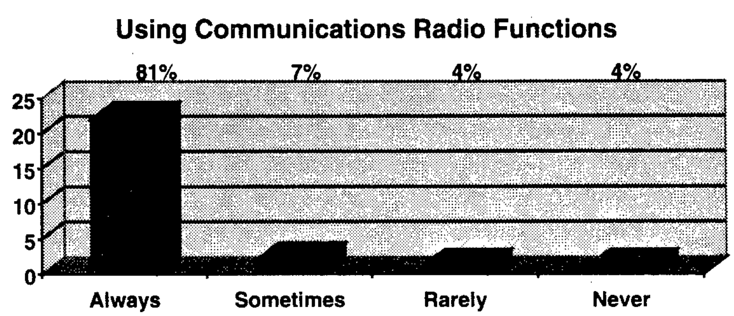
Pilots can display a moving map on the GX-60 display screen showing the position of airports, navaids, boundaries, and various geographical features (roads, waterways, etc.).



m

n. Using Communications Radio Functions

The GX60 includes a communications transceiver that has several advanced functions. It functions in the same manner as most aircraft transceivers, allowing the pilot to enter and select between active and standby frequencies.



n

o. Using the Monitor Function

The MONITOR function allows the selected standby frequency to be monitored. Any transmission on the ACTIVE frequency will override this function.

p. Using the Recall Function

The pilot can access a database of frequencies through the RECALL function. By selecting this function, the pilot can access frequencies referenced to the current To/From waypoints or destination, the last 10 frequencies used, the frequencies for the last time the NEAREST or INFO function was activated, user stored frequencies, weather frequencies, and the emergency channel (121.5).

Nine of the pilots stated that they had not received enough training, or no training at all on the use of this particular function. Eight other pilots said that the function was not necessary.

q. Using the Memorize Function

The MEMORIZE function allows the pilot to store any frequency in the database.

Eleven pilots thought the function unnecessary. Ten were unaware of the function. Only nine of the pilots (33%) stated they had received formal training regarding the function.

r. Selecting CDI Sensitivity

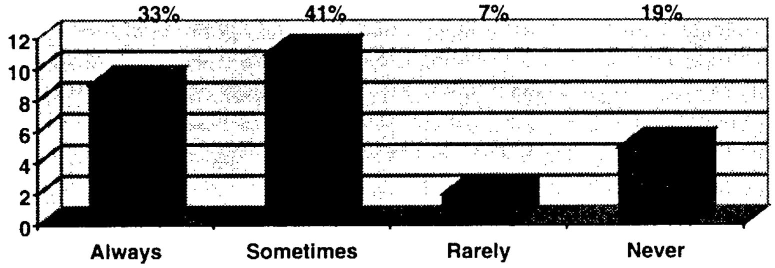
This function allows the pilot to manually select the number of miles represented by a full-scale deflection of the CDI. This is normally left at 5 miles for en route operations. During approach operations the CDI will automatically scale from 5 miles to 0.3 miles.

Ten pilots said the function was not necessary. Five were unaware of the function. Two pilots stated that no or not enough training was received for the function.

s. Customizing NAV pages

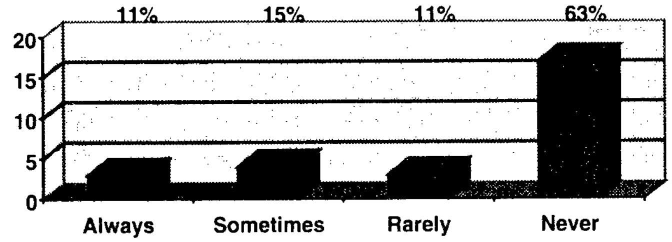
The GX60 allows the pilot to customize what types of navigation information will be displayed on the various NAV pages. He/she may select from items such as Desired Track, Bearing, Track Angle Error, an Electronic CDI, ETA, ETE, etc. These data can be displayed in many different combinations. Once these pages are set, the pilot can choose between scrolling through them manually or automatically.

Using the Monitor Function



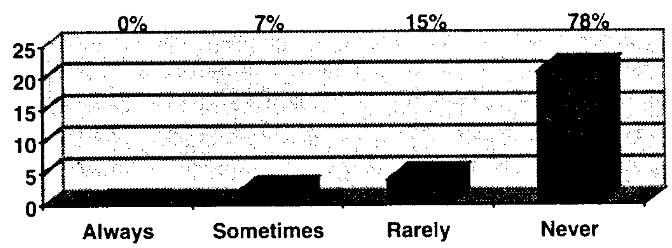
o

Using the Recall Function



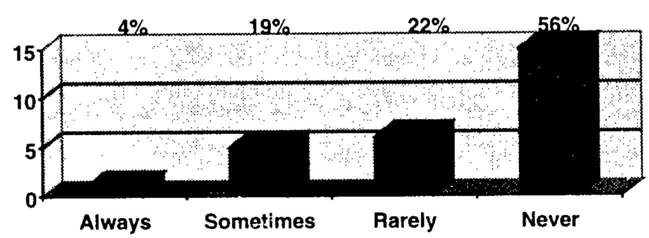
p

Using the Memorize Function



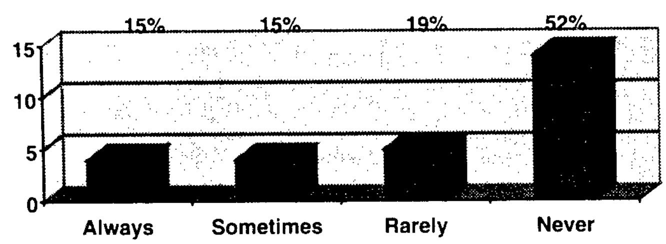
q

Selecting CDI Sensitivity



r

Customizing NAV Pages



s

Ten pilots claimed the function was not necessary. Four were unaware of the function. Ten (37%) stated that they had received formal training for the function.

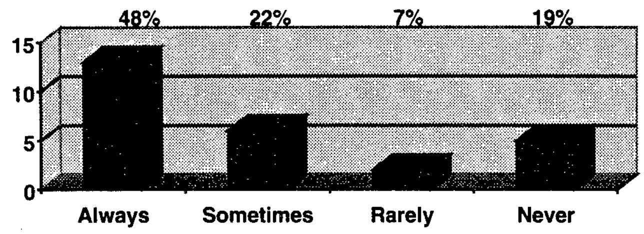
t. Selecting Direct-To Entry Options

This function allows the pilot to choose whether a DIRECT-TO entry will always clear the active flight plan. If set to YES, any DIRECT-TO will clear the active flight plan even if the entered waypoint is in the active flight plan. If set to NO, a DIRECT-TO to a waypoint in the flight plan will simply create another leg with DIRECT-TO as the FROM waypoint.

Figures 7a-t depict GX-60 function usage estimates.

Over half of the pilots that filled out the self-administered questionnaire (14 of 27) stated that they never used the flight planning function of the GX-60. Instead, they would use the nearest and/or direct-to function to navigate to each of the waypoints in turn. This behavior is probably due in large part to the type of flying that is performed in the Bethel area. Pilots do very little instrument flying. They also will usually navigate from one village to another using the direct-to function during each leg of the trip.

Selecting Direct-To Entry Options



t

Human Factors Design Issues

Pilots that filled out the self-administered questionnaire were asked to rate several aspects of both MX-20 multi-function display and the GX-60 GPS display. Responses ranged from 1 to 5 with 1 = "Unacceptable," 2 = "Marginally Acceptable," 3 = "Acceptable," 4 = "Very Acceptable," and 5 = "Excellent." Table 1 shows the MX-20 functions that were evaluated, along with the mean and standard deviation of the ratings across all participants. Table 2 shows the GX-60 functions that were evaluated, along with the mean and standard deviation evaluation across all participants. Highlighted items are those features that were evaluated as less than acceptable on average.

Table 1: MX-20 Function evaluation items with mean evaluation rating across participants.

MX-20 Function Evaluation Item	Mean	SD
Ease of reading map data	4.26	0.7642
Ease of reading and accessing of Text Weather data (METARS, TAFS)	**2.76**	1.3317
Ease of reading and using Traffic data	3.89	0.8006
Ease of accessing and using Terrain data	3.70	0.8689
Ease of accessing database information (runway lengths, frequencies, etc)	4.19	0.9214
Ease of using the function/item Select keys	3.92	0.7961
Ease of using the MX-20 under local environmental conditions	3.89	1.0127
Overall rating of the MX-20	4.15	0.9885

Table 2: GX-60 Function evaluation items with mean evaluation rating across participants.

GX-60 Function Evaluation Item	Mean	SD
Ease of reading the text on the screen	3.56	0.8916
Ease of use of function key/knobs	3.59	0.9711
Usefulness of the built in moving map	3.27	1.4016
Ease of accessing database information (i.e., runway lengths, frequencies, etc)	3.77	1.0318
Usefulness of the alerting functions (Waypoint crossings, airspace, etc)	3.31	1.0107
Ease of entering/editing Flight Plans	3.15	0.9672
Ease of entering/using user waypoints	3.19	0.9214
Ease of using the Approach functions	**2.89**	1.0485
Ease of using the Comm functions	3.77	0.7646
Using the GX-60 to conduct a non-precision approach	3.29	1.0690
Acceptability of the GX-60 under local environmental conditions	4.00	0.8771
Overall rating of the GX-60	3.88	0.9364

In general, pilots rated most functions as acceptable or higher for both the MX-20 and GX-60 units. The lowest rated item for the MX-20 was the ease of reading and accessing textual weather data. For the GX-60 the lowest rated item was the ease of using the approach functions. Both of these functions are not used regularly by pilots in the Bethel area, as is attested to by the usage estimates for those functions given in Figures 5 and 6. A paired t-test was conducted to compare the overall rating of the GX-60 with the overall rating of the MX-20. The result showed that the MX-20 was rated higher than the GX-60 at a marginal level of significance, $t(27) = 2.033, p = 0.052$.

Multi-function Display Page Hierarchy (MX-20 Display)

Pilots reported that the Terrain mode was a minimum of 2 button activations away from the Custom Map page. Since many pilots preferred to quickly switch back and forth from the Custom Map page to the Terrain page, the 2-button push and heads down time required to perform this task was considered quite undesirable and a potential safety hazard.

One common complaint expressed about the traffic display (5 pilots) was that the dedicated Traffic page should be one button push away from the Map page and other major pages. As currently designed, this system required a minimum of 2 button activations to access the dedicated traffic page. Pilots were concerned about the amount of heads-down time and having to divert their attention from other cockpit tasks. The few extra seconds required to select the dedicated traffic page, especially when flying close to the surface or when weather conditions were poor, was objectionable.

The effect of MFD information hierarchy decisions on pilot performance has been demonstrated by other researchers (Roske-Hofstrand & Paap, 1986; Reising & Curry, 1987; Sirevaag et al., 1993). It is critical that attempts be made to optimize display page organization so as to maximize pilot performance with the displays. While there have been attempts to develop structured approaches to the design of an optimal display hierarchy (e.g., Francis, 2000; Roske-Hofstrand & Paap, 1986), it is likely that the process will remain iterative. Feedback from users of the systems will remain a critical part of the organization of the menu and display structure of these systems.

Availability of Information Key

There is a need to provide a key to pilots to inform them of the meaning of the colors used in the relative terrain display mode. Four of the pilots, during their interview, admitted that they did not know the exact meaning of the four relative terrain colors (red, yellow, green, and black).

Overlaying Information

Typically, the terrain mode is not used in normal day-to-day operations. The primary reason for this is that with the display of this information the pilot must forfeit topographical information, along with airport, navigation aids, airways, and other types of information that may be displayed on the Custom Map page. Some pilots reported that they would periodically switch back and forth between the Custom Map page and the Terrain Page when in marginal visual conditions to maintain better situation awareness. However, since the Custom Map page provided such good position awareness, most pilots simply flew with that page selected unless they were in or near hazardous terrain or visibility was near zero. Consequently, pilots expressed the desire to display relative terrain with topographical and other navigational data.

Five pilots mentioned that the magenta route line on the MX-20 display would sometimes obscure traffic information such as the altitude of other aircraft. It was suggested that the priority of the traffic information be increased so that it would not be obscured by a portion of the route line.

Auditory Alerts

Presentation of only a visual alert for warning the pilot of impending hazardous terrain ahead was not adequate. One pilot noted that unless he was watching or continuously checking the display, a terrain alert could be generated and not noticed for some length of time. For such critical safety related information, an aural alert should accompany a terrain warning to ensure timely pilot awareness. However, there is a likelihood that a continuous warning sound would become extremely annoying to pilots and would, therefore, be turned off permanently.

Zooming and Panning Problems

Two pilots complained that when viewing information on the dedicated traffic display, they were required to change the zoom level and/or pan to a different portion of the map to see a particular aircraft. After changing the zoom level and/or panning, they would return to the original map screen with the new zoom/pan conditions in effect. They were then required to re-adjust the display to obtain the original zoom/pan conditions. This required several button presses to accomplish.

Better Logic for Traffic Warnings

Four of the pilots suggested changes in the display of traffic warnings that could reduce the number of warnings received by the pilots and/or improve the information the pilot receives. One pilot suggested highlighting traffic on the display that triggered the warning so pilots could more quickly react. A second pilot suggested having some sort of indication of the direction of threatening traffic (such as a popup arrow). One pilot suggested certain types of transponder-related information be included with the traffic symbology, specifically "emergency," "lost communication," or "hijack" information.

RECOMMENDATIONS AND CONCLUSIONS

Training Recommendations

Using Conventional Navigation Instruments

Referring back to Figure 3, several of the pilots who claimed there had been no loss of navigational skill said that they used the conventional navigation instruments consistently during most flights as a backup. In a separate question, 80% of the pilots (32) indicated that they used conventional navigational instruments as a secondary source of navigation information while flying Capstone-equipped aircraft. It is recommended that, during training, pilots are encouraged to continue using their conventional navigation instruments. This should help to maintain skills with those instruments and would also provide adequate navigational information to the pilot if the moving map or GPS display should fail.

Mixed Equipage Training

During training, instructors should periodically emphasize that not all aircraft in an area will be equipped with ADS-B technology. The pilots must learn not to rely too heavily on the traffic display to ensure that there is no traffic in the area. In addition, it might be useful to conduct research regarding how different levels of equipage in a particular region will affect pilot reliance on the traffic display.

Training to Avoid Traffic

There are established maneuvers that pilots use to avoid oncoming traffic. These maneuvers should be emphasized during training so that potential traffic conflicts can be resolved quickly. Some of the pilots commented that even though they could see potentially conflicting traffic on their displays, there were times when the maneuvers of both pilots would not quickly resolve the conflict, but instead would keep the planes on a collision course. Review of standard avoidance maneuvers should eliminate these situations.

Risk-Taking and Aeronautical Decision-Making

The potential abuse of these displays remains high, and part of the training should focus on encouraging the pilot not to use the displays to "push the envelope."

Design Recommendations

Minimizing Control Inputs

- Stand-alone GPS receivers and traffic and terrain awareness systems must be designed for ease of use. Minimum performance standards should be developed that define pilot interface requirements in terms of task complexity, number of actions, reliance on memory and time-to-perform.
- All primary pages (moving-map, traffic, weather, relative terrain) should be available with a single button press.
- Zooming and panning functions should be independent between pages, or a means should be provided to discard the changes and return to original zoom and pan settings.
- Users should not be required to enter barometric pressure more than once during system updates.
- Barometric pressure entry on the MX-20 would be much easier and faster with a knob instead of push buttons.

Use of a Display Information Key

Displays showing relative terrain should contain a readily available color code key. This information should be accessible so pilots do not have to search for it within the menu structure.

Information Overlay Issues

- Manufacturers should be encouraged to design systems that permit the overlay of terrain data over other types of topographical and navigational data.
- The depicted course line sometimes obscures traffic information, such as the traffic altitude. While it is true that navigation should be primary on a display, it makes sense to allow a portion of the course line to be covered by pertinent textual information, such as traffic altitudes, since such obscuration would not affect the basic information conveyed by the course line.
- In the track-up display mode, heading information is displayed at the top of the moving map display. Locating the heading at this position means that it will obscure a portion of the depicted course. It is suggested that the heading information be located elsewhere on the display so that as much of the course line as possible can be presented to the pilot.

Aural Alerts

For safety critical information such as cautions and warnings of terrain hazards, visual cautions and warnings should be accompanied by an associated aural caution and warning.

Additional Design Features for Consideration

Manufacturers designing similar avionics should consider implementing the following features:

- Altitude-filtering of traffic with a 500 foot resolution;
- Improved traffic threat information;
- Simpler flight plan entry.

Other Issues

Accuracy of Terrain Database

Accuracy of the terrain database is critical to the effectiveness of these displays.

Availability of Weather Information

Pilots did not make much use of the depiction of weather, either graphical or textual, because this information was not available very often. It is likely that there is a critical level of availability that must be achieved for pilots to get into the habit of utilizing this information. If availability does not achieve this critical level, pilots will simply not incorporate the checking of weather displays into their flight routines. The critical level of availability is not known at this time.

Pilot Demographics

The pilot population in the Bethel area is probably slightly different from the general pilot population in terms of demographics. The average age of the Bethel pilots was 37, whereas in the pilot population of GA pilots the average is approximately 45 (FAA, 2000). The percentage of instrument-rated pilots was 95% for the Bethel pilots, which is much greater than the approximately 30% of pilots with instrument ratings in the private pilot population (FAA, 2000). Finally, although we do not have statistics to verify the statement, it is likely that the Bethel pilots fly much more often than the general aviation pilot population. All of these differences could have an impact on the ability of pilots to remain proficient with these types of displays.

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[1]All Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publications Web site: http://www.cami.jccbi.gov/aam-400A/index.html

APPENDIX A

Demographic Data Form

Part I – Demographics------To be completed by each pilot

General	
Male	
Female	
Age	
Previous Occupation	
Years of Education past high school	
Field of Study	
Personal Computer User level	Advanced (programming, application development) General (office use, word, excel) Basic (Internet, Email) None

Ratings and Certificates	
Private	
Commercial	
Airline Transport Pilot	
Single Engine Land	
Single Engine Sea	
Multi Engine Land	
Multi Engine Sea	
Glider	
Rotorcraft	
Instrument	
Certified Flight Instructor	
Certified Instrument Instructor	
Multi Engine Instructor	
Ground Instructor	
Advanced Ground Instructor	
Please list type ratings held:	

Commercial pilot experience	
Years of Part 91 experience (flight instruction, corporate, etc.)	
Years of Part 135 experience	
Years Part 137 (AG)experience	
Years of Part 121 experience	

Flight Time Estimates	Total	Last Year
Hours Logged:		
Civilian Hours:		
Military Hours:		
Day VFR		
Night VFR		
Day IFR		
Night IFR		

GPS experience	Approx. Hours of Use	Please List Model Names with which you have any experience.
Handheld GPS		
Panel Mount GPS under VFR		
Panel Mount GPS under IFR		
Loran		
TCAS		
FMS		
MFD (MultiFunction Display)		

APPENDIX B

Interview Form

Pilot Operations

1. In flying a non-capstone-equipped airplane, I generally navigate by:

P=Primary S=Secondary N=Not Used

Method	**Rating**
Charts and Landmarks	
Headings and Times	
Radio Aids	
Other GPS	

2. In flying a Capstone equipped airplane, I generally navigate by:

P=Primarily S=Secondary N=Not Used

Method	**Rating**
GX-60 only (MX20 turned off or not referred to)	
MX-20 only(just follow the magenta line)	
GX-60 and MX-20 together	
Charts and Landmarks	
Heading and Time	
Radio Aids	
Other GPS	

3. Under what circumstances (if any) is the Terrain Mode most useful?

4. Under what circumstances (if any) is the Terrain mode distracting, confusing or dangerous?

5. What suggestions do you have for making the Terrain mode more useful?

6. What effect (if any) will the Capstone equipment have on controlled flight into terrain accidents?

___Significant reduction
___Moderate reduction
___Slight reduction
___No reduction
___Increase

7. Under what circumstances has the presentation of Traffic proved most useful?

8. Have you ever preferred NOT to display the traffic? (yes/no), If so, under what circumstances?

9. What suggestions do you have for making the Traffic presentation more useful?

10. What effect (if any) will the Capstone equipment have on the rate of near mid air collisions?

___Significant reduction
___Moderate reduction
___Slight reduction
___No reduction
___Increase

11. Have you ever been asked to operate the Capstone equipment during a flight check? If so, what Capstone functions were you asked to perform?

12. Rate the amount you feel your conventional navigational skills have been affected as a result of using Capstone avionics?

1- significant deterioration of conventional skills
2
3- some deterioration of conventional skills
4
5- no affect
6
7 -some improvement of conventional skills
8
9- significant amount of improvement of conventional skills

13. Has the Capstone equipment ever alerted you or anyone you know to a potential conflict with traffic or terrain that would likely have otherwise resulted in an accident? If yes, please describe the incident.

14. Has the Capstone equipment ever alerted you to a navigational error? If yes, please describe the incident.

15. Has the Capstone equipment ever helped you handle any other potentially serious situation? If so please describe the incident.

16. Has your or another's use of the Capstone equipment ever created a hazardous situation? If so please describe it.

17. Have you ever noticed a GPS bearing error or timeout error on the GX-60? or any other problems in the functioning of the GX-60 or MX-20? If so, please describe the problem and say whether it was flagged by the GPS unit.

18. What effect, in your opinion, has the Capstone equipment had, or will it have on risk-taking behavior (Check all that apply).

___ Some pilots will be more likely to fly under lower visibility conditions.
___ Some pilots will be more likely to fly at lower altitudes (closer to the ground) under low visibility conditions.
___ Some pilots will be more likely to fly closer to hazardous terrain features (mountains, hills) under low visibility conditions.
___ Some pilots will be more likely to fly through hazardous mountain passes when weather is questionable or visibility is low.
___ Some pilots will be more likely to fly closer to other aircraft even if it is difficult to maintain constant visual awareness of their position.
___ Other (Briefly describe) ____.
___ It will have absolutely no affect on it risk-taking behavior.

19. What are the most significant safety hazards associated with this equipment?

APPENDIX C

Self-Administered Questionnaire

Feature Use-MX-20

Features	**Feature Use in Day to Day Operations** **A=Always** **S=Sometimes** **R=Rarely** **N= Never**	**If Feature is Never used , why:** **1- Not applicable or necessary to my operation** **2- No or not enough training** **3- Complexity of feature** **4- Not aware of feature** **5- Other (please state reason)**	**Training Method for features that are used, list all that apply** **F – Company/UAA provided formal training** **M- Self Study with Manual and equipment** **S - Capstone or PC simulation.** **P- Another pilot showed me.** **N- No Training**
Selecting the Map Type (VFR,IFR, Custom)			
Selecting the Map Orientation (North up, Track up, etc)			
Selection of map data to display/decluttering			
Range selection(Zoom)			
Selecting Range Defaults(Ground, Flight)			
Use of the PAN mode			
Acquiring Database information (INFO)			
Using the Graphic Traffic Screen			
Using the Text Traffic Screen			
Individual Target Selection			

Features	Feature Use in Day to Day Operations A=Always S=Sometimes R=Rarely N= Never	If Feature is Never used , why: 1. Not applicable or necessary to my operation 2. No or not enough training 3. Complexity of feature 4. Not aware of feature 5. Other (please state reason)	Training Method for features that are used, list all that apply F – Company/UAA provided formal training M- Self Study with Manual and equipment S- Capstone or PC simulation. P- Another pilot showed me. N – No Training
Target Altitude display (relative, absolute)			
Modifying the broadcast information(Privacy mode)			
Terrain Modes (relative,sectional dedicated Screen)			
Weather Screen			
Flight Information Service Screen			
Using the FlightPlan Screen			
Using the Message Screen			

Feature Use-GX-60

Features	Feature Use in Day to Day Operations A=Always S=Sometimes R=Rarely N= Never	If Feature is Never used , why: 1- Not applicable or necessary to my operation 2- No or not enough training 3- Complexity of feature 4- Not aware of feature 5- Other (please state reason)	Training Method for features that are used, list all that apply F – Company/UAA provided formal training M- Self Study with Manual and equipment S- Capstone or PC simulation. P- Another pilot showed me. N – No Training
Entering/Copying/Saving/Deleting/Editing Flight Plans			
Viewing ETA's ETE's, Waypoint Distances			
Direct To Function			
Database/INFO functions			
Loading/Unloading/ Changing and Flying IAPs			
RAIM Prediction			
Flying specific radials to/from waypoints			
Storing and using User defined Waypoints			
Holding (Hold,Continue, Functions)			
Parallel Track Offset			
Nearest Functions			
Viewing Messages			
GX-60 Moving Map			
Comm radio			
Comm radio Functions: Monitor Function			
Recall Function			
Memorize Function			
System Functions: Selecting CDI sensitivity			
Customizing NAV pages			
Direct To Entry Options			

Equipment Design-MX-20

Please rate the following on this scale:

0=Don't Know
1 = Unacceptable
2 = Marginally Acceptable
3=Acceptable
4 = Very Acceptable
5=Excellent

	Rating	Comments
Readability of map data		
Readability and accessability of Text Weather data		
Readability/Usability of Traffic data		
Usability of the Terrain data		
Accessibility of database information		
Ease of using the function//Item Select keys		
Acceptability of the MX-20 under local environmental conditions		
Overall rating of the MX-20		

Equipment Design GX-60

Please rate the following on this scale:

0=Don't Know
1 = Unacceptable
2 = Marginally Acceptable
3=Acceptable
4 = Very Acceptable
5=Excellent

	Rating	Comments
Readability of textual data		
Ease of use of function keys/knobs		
Usability of built in moving map		
Accessibility of database information		
Acceptability of alerting functions (Waypoints, airspace, etc)		
Acceptability of Flight Plan Entry/Editing functions		
Acceptability of User Waypoint functionality		
Acceptability of Approach functions		

	Rating	**Comments**
Acceptability of the Comm functions		
Usability of the GX-60 to conduct a non-precision approach		
Acceptability of the GX-60 under local environmental conditions		
Overall usability of the GX-60		

Pilot Preferences and General Questions - MX-20

Approx percentage of time spent in each Map orientation mode	**Track-Up**		**North-Up**	**Track-Up 360**	**Track-Up Arc**
Approx percentage of time in each Terrain Mode	**Sectional page**		**Relative Mode**	**Dedicated Terrain Page**	**None**
Approx percentage of time spent in each Chart/Traffic mode	**VFR**	**IFR**	**Custom(MAP)**	**Graphic Traffic**	**Text Traffic**
If you use a particular range setting for a particular phase of flight please list them.					
Under what circumstances do you use the PAN mode?					
Do you normally correct the MX-20 altimeter setting when the system requests it?					
Were you supplied with a personal MX-20 user manual?					

Pilot Recommendations and Comments:

Pilot Preferences and General Questions- GX-60

Do you customize your NAV page data? If so- list data displayed on primary NAV page.	
Is the GX-60 interfaced to an external HSI/CDI on any aircraft you typically fly?	
Is the GX-60 coupled to the autopilot on any aircraft you typically fly?	
Is the GX-60 coupled to a Fuel Computer on any aircraft you currently fly?	
Were you supplied with a personal GX-60 users manual?	

Pilot Recommendations and Comments: